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정렬과 평균 정규화를 이용한 2D ECG 신호 압축 방법

(2D ECG Compression Using Optimal Sorting Scheme)

이 규 봉****, 주 영 복*, 한 찬 호**, 허 경 무***, 박 길 흠****

(Kyu-Bong Lee, Young-Bok Joo, Chan-Ho Han, Kyung-Moo Huh, and Kil-Houm Park)

요 약

이 논문에서는 효율적인 2D 방식의 심전도 신호 압축 방법을 제안한다. 1D 심전도 신호는 2D 신호로 변환된 후 주기와 복잡도를 바탕으로 정렬되고 상호간의 상관 관계를 적용한다. 그 다음 불연속이 발생하는 지점을 기준으로 각 구간을 분할하고 주기의 평균으로 정규화 한 후 보통의 영상 신호를 압축하는 방식과 유사한 방식으로 정렬된 2D 신호를 압축한다. 압축 방식으로는 JPEG 2000이 사용되었으며 실험 데이터는 심전도 압축에서 표준화되어 사용되는 MIT-BIH arrhythmia database를 사용하였다. 제안된 방법은 기존의 2D 심전도 압축 방식과 비교하여 보다 개선된 성능을 보여 준다.

Abstract

In this paper, we propose an effective compression method for electrocardiogram (ECG) signals. 1-D ECG signals are reconstructed to 2-D ECG data by period and complexity sorting schemes with image compression techniques to increase inter and intra-beat correlation. The proposed method added block division and mean-period normalization techniques on top of conventional 2-D data ECG compression methods. JPEG 2000 is chosen for compression of 2-D ECG data. Standard MIT-BIH arrhythmia database is used for evaluation and experiment. The results show that the proposed method outperforms compared to the most recent literature especially in case of high compression rate.

Keywords : Electrocardiogram compression, Period sorting, Mean normalization, 2-D correlation

Ⅰ. Introduction

Variety of ECG compression methods have been pro-posed with satisfactory performance[1~9]. Most of the methods use 1-D representation for ECG signals such as long-term prediction, vector quantization (VQ) or wave-let transform[7~9]. However, many 1-D methods do not fully utilize inter beat correlation. It has been attempted to transform 1-D ECG signal into 2-D ECG data to get the most of benefit from both the inter and intra-beat correlation[1~6]. The basic idea of 2-D ECG signal compression is that we want to treat ECG signals as the same way we treat an ordinary digital image in the conventional image compression methods. Lee and Buckley constructed 2-D ECG and applied DCT transform to that, Bilgin et al. applied JPEG2000, Tai et al. applied SPIHT algorithm and their works have achieved better results than 1-D compression methods[4~6]. Several authors have successfully used period normalization[1, 3~4], which has led to significant improvements. However, there are factors that prevent the

* 정회원, 연세대학교
(Yonsei University)
** 정회원, 강원대학교 방송영상학부
(Department of Broadcasting Visual media and Technology Kangwon National University)
*** 정회원, 단국대학교 전자공학과
(Department of Electronics Engineering Dankook University)
**** 정회원, 경북대학교 전자전기컴퓨터학부
(Department of Electrical Engineering and Computer Science Kyungpook National University)
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normalized periods from having high correlations, which may compromise the performance of the compressor. Also their compression performance dropped in cases of irregular ECG signals mainly because they cannot reduce high frequency redundancies among adjacent beats. Beat segment sorting methods are proposed such as period and complexity sorting schemes[1~2]. Period sorting reorders beat segments based on the length of each segment. Complexity sorting uses MSE (Mean Square Error) to sort beat segments. These 2-D ECG compression methods with sorting schemes have been reported to perform better than conventional 2-D ECG compression methods[1~2]. But weaknesses still remain such as in-crease of data size to encode, efficiency of sorting and so forth. In this paper, we propose an effective compression method to overcome the weaknesses of the conventional 2-D ECG compression methods. The paper is organized as follows. Section II describes conventional 2-D ECG compression methods with sorting schemes and their drawbacks. Section III explains our proposed method. Section IV demonstrates experimental results and analysis. Finally Section V summarizes and concludes this paper.

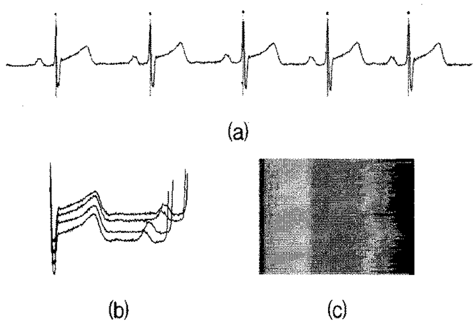

그림 1. 1D 심전도 신호로부터 2D 심전도 신호로 변환되는 과정, (a) 1D 심전도 신호, (b) 접합 그리고 (c) 변환된 2D 심전도 데이타

Fig. 1. Illustration of trasformation to 2-D ECG data from 1-D ECG signals (a) 1-D ECG signals, (b) concatenation and (c) 2-D representation.

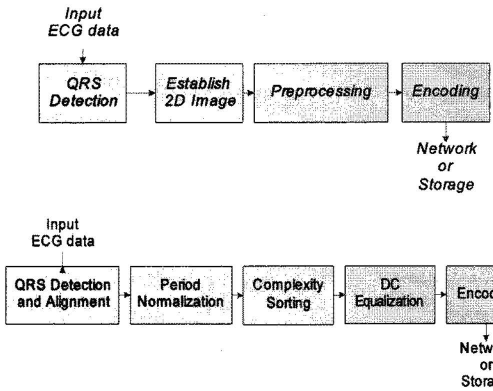

그림 2. 기존의 심전도 신호 정렬 방법

Fig. 2. Conventional ECG segment sorting methods.

II. Convetional ECG Compression Methods

1. Conventional ECG compression methods

2-D ECG data is regarded as a normal image in 2-D ECG compression methods. Original 1-D ECG signals are transformed into 2-D ECG data representation. The transformation process is depicted in fig. 1. The transformed 2-D ECG signal is regarded as a normal image and it follows the same procedure as we compress a digital image. The conventional 2-D ECG compression process is illustrated in fig. 2. In spite of their high performance, the conventional ECG segment sorting based ECG compression methods have some weaknesses. Firstly, high frequency redundancies among adjacent beats still remain. Secondly, misalignment of QRS complex position may occur due to period sorting. The third weakness is that normal and abnormal beats can be mixed together after period sorting when the length of the beats is similar to each other. Finally, period normalization generally increases the size of image for compression especially when we normalize the beats based on the longest beat. This obviously degrades the overall performance of the compression.

III. Proposed Methods

1. QRS complex detection and alignment

QRS complex detection is necessary for beat based compression scheme. We propose an appropriate scheme for decision on stating position. In this method, each QRS peak position of each segment is placed and aligned properly.

2. Complexity sorting, beat grouping and period sorting

The sorting index is chosen by complexity sorting methods and the beats rearranged based on the sorting index. After complexity sorting beat segments with similar shapes are grouped. In this step we decide on the boundary of each group using image processing techniques such as median filter or Sobel operation[9]. Beat grouping algorithm can be described as follows: period normalization, noise reduction, edge detection, boundary decision. Period normalization uses B-spline interpolation to make length of each beat segment same. We solve this problem by applying period sorting technique to each group.

3. Division of blocks

Each group is divided into three blocks. First block consists of the first k number of samples before QRS peak is positioned. Second block indicates middle position. The third block starts at the last sample of the shortest beat segment in the group.

4. Period normalization and block-based normalization

There exist blocks filled with dummy data due to different length of period. Each horizontal line ofthose blocks is expanded using B-spline interpolation. Adjacent lines may have different DC levels which results in lines may have different DC levels which results in high frequency components along the vertical direction of the resulting image and it decreases the efficiency of a compression system. Conventional mean normalization scheme improves this problem to some extent but there is still more room for enhancement. In order for further improvement, we devised block-based mean normalization procedure.

5. JPEG2000 encoding

Each group is encoded using JPEG 2000 compression scheme for the purpose of suppression of high frequency around boundary area between groups for better compression performance. The Proposed 2-D ECG compression process is illustrated in fig. 3 and fig. 4 shows an example of process of the proposed method.

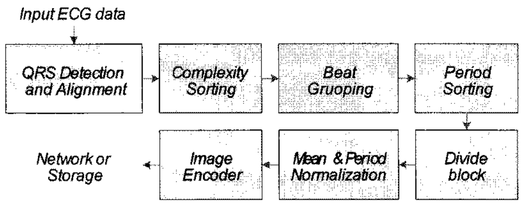

그림 3. 제안된 2D 심전도 압축방식의 흐름도
Fig. 3. Flow chart of the proposed method.

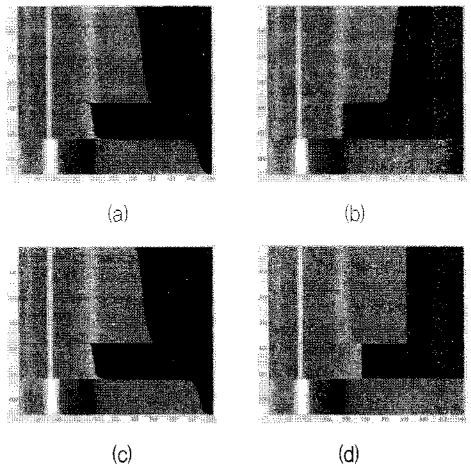

그림 4. 제안된 압축방식의 예, (a) 변환된 2D 심전도 데이터, (b) 복잡도 기준 정렬 후 데이타, (c) 주기 기준 정렬 후 데이터 그리고 (d) 구역 기준 주기 평균 정규화 후 데이타
Fig. 4. An Example of proposed method, (a) constructed 2-D ECG image, (b) image after complex sorting, (c) image after period sorting by groups, (d) image after period normalization and block based mean equalization.

IV. Experimental Results

1. Performance criteria

Two measurements are introduced for comparing performances of the proposed methods to other competitive algorithms: CR (Compression Ratio) and PRD (Percent Root mean squared Difference).

$$CR = \frac{\text{The number of bits in the original 1-D ECG signal}}{\text{The total number of bits in the compressed data}}$$

$$PRD = \sqrt{\frac{\sum_{i=1}^{L}(x_{org}(i) - x_{rec}(i))^2}{\sum_{i=1}^{L} x_{org}(i)^2}} \times 100\%$$

where *xorg(i)* is original ECG signal, *xrec(i)* is compressed and reconstructed signal and *L* is size of signal.

2. Experimental results

For evaluation of coding efficiency of the proposed method, we conducted experiments with the first 216, 000 samples from records 100, 117, and 119 in the MIT-BIH ECG database. The signals are sampled at 360 Hz with 11-bit of sampling resolution. Fig. 5 shows the proposed method shows higher performance than the methods recently reported methods in terms of compression ratio and reconstruction error.

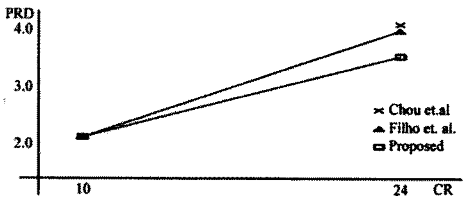

그림 5. 기존 2D 심전도 방식과의 성능 비교표
Fig. 5. Performance comparison among various ECG compression schemes record 100.

V. Conclusion

In this paper, we propose an effective 2-D based ECG compression method. 1-D ECG signal is reconstructed to 2-D data using complex and period sorting schemes to increase inter and intra-beat correlation. 2-D data are divided into groups and blocks followed by mean normalization. JPEG2000 is chosen as a codec scheme. The proposed method reduces extra high frequency redundancy between adjacent beat segments for more efficient 2-D ECG data. Proposed method generates extra data called side information such as sorting, block, mean information and so on. In spite of the increase of side information, the proposed method outperforms the methods described in the literature especially in case of high compression rate.

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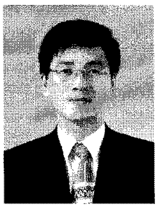
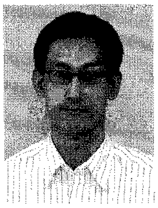
저 자 소 개

이 규 봉(정회원)
2002년 경북대학교 전자전기 공학부 학사
2004년 경북대학교 전자공학과 석사
2004년～현재 경북대학교 전자공학과 박사과정
<주관심분야 : 영상처리, 컴퓨터 비전, 얼굴인식>



한 찬 호(정회원)
1990년 경북대학교 전자공학과 학사.
1992년 경북대학교 전자공학과 석사.
2003년 경북대학교 전자공학과 박사.
1992년 현대전자 미디어연구소 주임연구원.
2000년 경운대학교 멀티미디어공학부 전임강사.
2006년 경북대학교 전자전기컴퓨터공학부 BK 교수
2009년～현재 강원대학교 방송영상학부 조교수
<주관심분야 : 임베디드 시스템, 디지털 TV, 멀티미디어>

박 길 흠(정회원)
1982년 경북대학교 전자공학과 학사.
1984년 한구과학기술원 전기전자 공학과 석사.
1990년 한국과학기술원 전기전자 공학과 박사.
2009년 현재 경북대학교 전자전기컴퓨터공학부 교수.
<주관심분야 : 영상신호처리, 패턴인식, 영상압축>



주 영 복(정회원)
1989년 연세대학교 전산과학과 학사.
1991년 연세대학교 전산과학과 석사.
1997년 UNSW 컴퓨터공학과 석사.
2001년 UNSW 컴퓨터공학과 박사.
2003년 UWA 컴퓨터학과 초빙연구원.
2008년 경북대학교 전자전기컴퓨터공학부 BK 교수
2009년～현재 연세대학교 전산과학과 연구교수
<주관심분야 영상신호분석 및 처리, 자동결함검사시스템>

허 경 무(정회원)
1979년 서울대학교 전자공학과 학사 졸업.
1981년 한국과학기술원 전기 및 전자공학과 석사 졸업
1989년 한국과학기술원 전기 및 전자공학과 박사 졸업
1993년～현재 단국대학교 전자공학과 교수,
단국대 전자부품 검사자동화 지역혁신센터(RIC) 소장,
대한전자공학회 시스템및제어 소사이어티 부회장,
<주관심분야 : 시스템 제어, 머신 비전, 검사자동화, 로봇제어, 학습 제어>